# Accounting Initial Condition Uncertainties in NEPS

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# NWP & its limitations

- In NWP, model forecast provides an estimate of the future state of the atmosphere. It is based on current state of the atmosphere which is created using observations - and then calculate the evolution of the atmosphere for the future state using the NWP model.

- Due to inadequate observations, our limited understanding of the physical processes of the atmosphere, and the chaotic nature of the atmospheric flow, uncertainties always exist in both initial conditions and numerical models

## NWP is strongly sensitive to the initial conditions

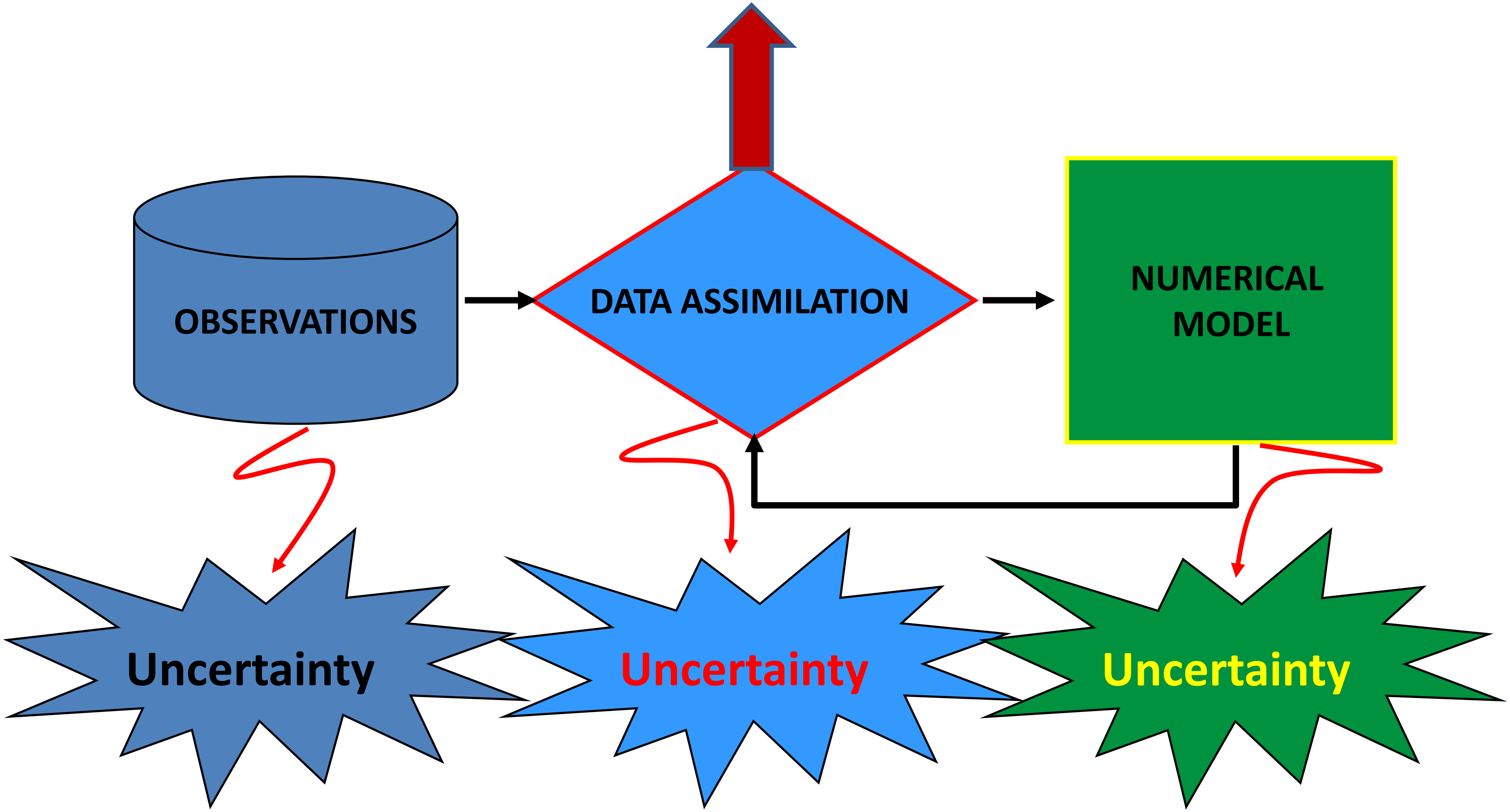
- As the atmosphere is a chaotic system, very small errors in its initial state can lead to large errors in the forecast.
- This means that we can never create a perfect forecast system because we can never observe every details which is required to create perfect initial state for the model.
- **So always there will be uncertainties in the single (deterministic) forecast**

# Data Assimilation

**"Data Assimilation" is the process in which available information is used to estimate the "state of a system" as accurately as possible.**

**Atmospheric data assimilation systems combine together information from a NWP model short term forecast, a set of observations (and other information) to estimate the "state of the atmosphere" called "analysis".**

# Analysis/Initial Condition



# How to Beat the Uncertainties

**ENSEMBLE FORECAST**

- Instead of using only one model with a single set of initial conditions, a group of forecasts with slightly different initial conditions are made in an ensemble forecast.
- **The initial condition differences between the ensemble members should be consistent with uncertainties in the observations.**

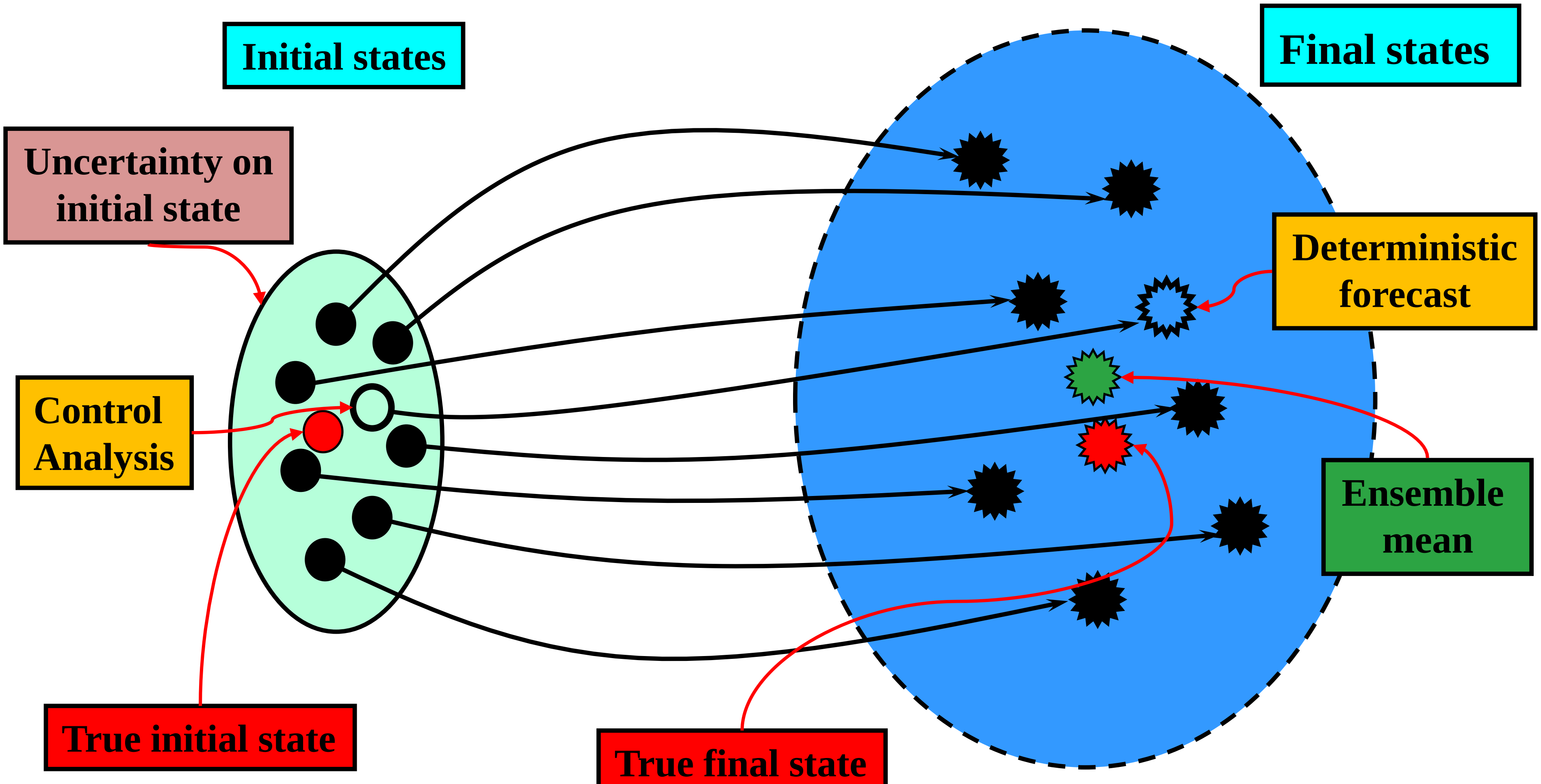
An ensemble usually includes the **control forecast** which is the one starting from the control analysis (the best estimate based on available observations) of the atmospheric state.

Other members in the ensemble are generated by adding perturbations (or errors) to the control analysis.

There are different ways to generate initial condition perturbations - Breeding of Growing Modes, Singular Vector method, Ensemble Transform Kalman Filter (ETKF) etc...

**In NCMRWF NEPS system, initial conditon perturbations are calculated using ETKF method**

# Ensemble Forecasting – Basic Concept

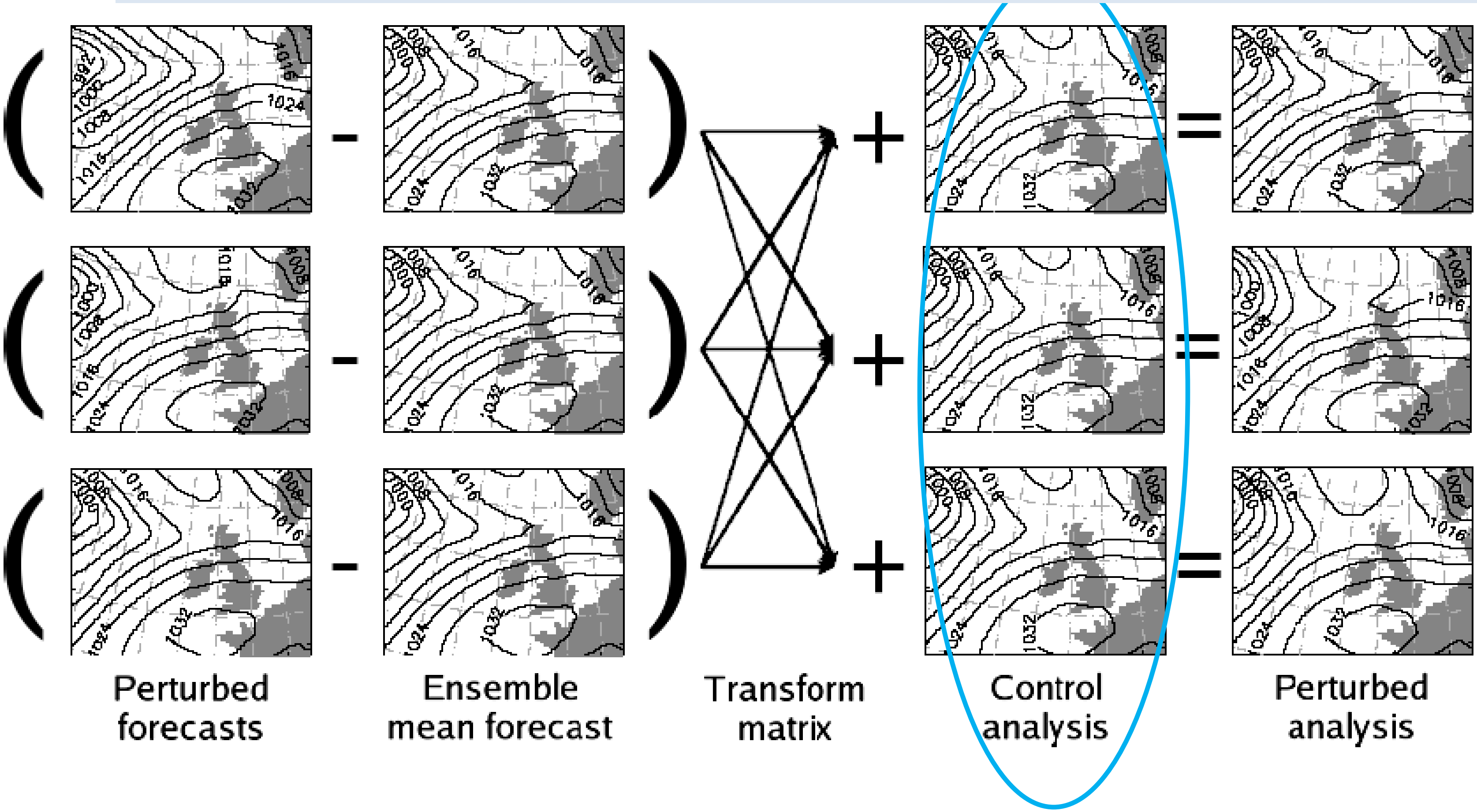


# Ensemble transform Kalman filter (ETKF)

- **ETKF – Simplified version of Ensemble Kalman Filter**

- **In ETKF, ensemble of analyses is calculated by transforming the background states of the previous cycle. ie, ETKF transforms the forecast perturbations into analysis perturbations by a transform matrix**
- **The transform matrix in the ETKF rotates and rescales the forecast perturbations based on the observational information**
- **In the NEPS ensemble prediction system of NCMRWF, the analysis perturbations are added to the control analysis created by Hybrid-4DVAR DA system to provide the initial conditions for the ensemble member forecasts.**

# Ensemble Initial Condition Preparation - ETKF

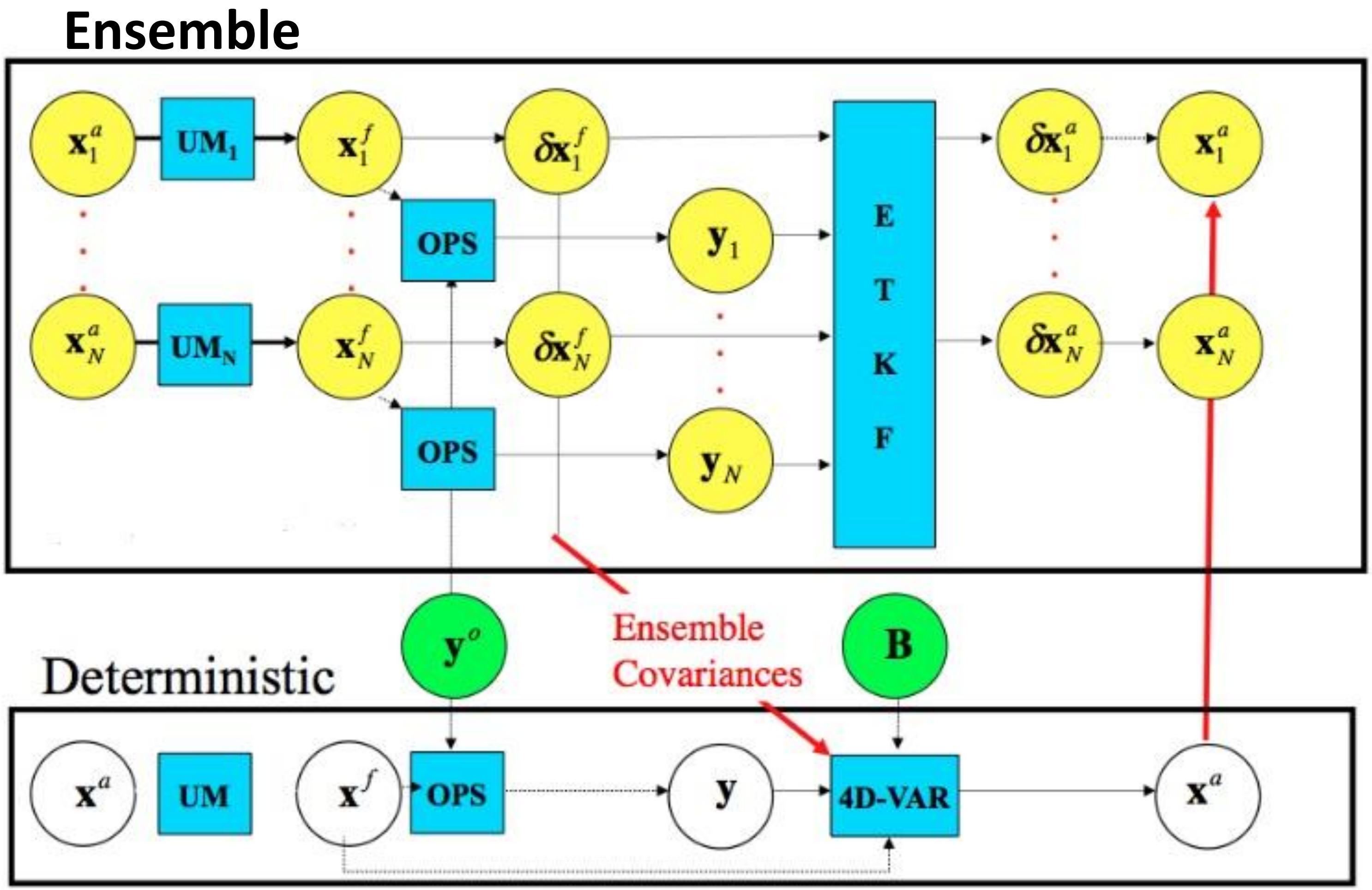



**ETKF method transforms the forecast perturbations into analysis perturbations by a transformation matrix**

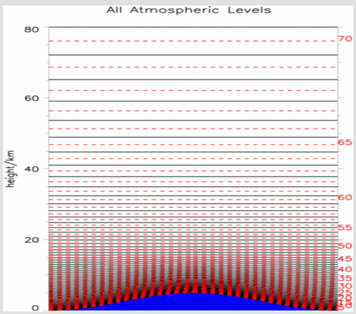
In the NEPS , the ETKF cycles are running every 6 hr for all the 22 members

**Figure from Bowler et al., The MOGREPS short-range ensemble prediction system, Q. J. R. Meteorol. Soc.134: 703 – 722 (2008)**

# Deterministic & Ensemble DA System




Source: UK Met Office




*Model Levels*

# Global NCUM NWP System (12 km resolution)

## Atmospheric Data Assimilation (Hybrid 4D-Var)

**Resolution: N320L70 (~40 km) with N144L70 Hessian based pre-conditioning**

## Method: Hybrid incremental 4D-Var. Information on "errors of the day" is provided by NEPS forecast at every data assimilation cycle

**Data Assimilation Cycles: 4 analyses per day at 00, 06, 12 and 18 UTC. Observations within +/- 3 hrs from the cycle time is assimilated in respective DA cycle**

**Observation Processing System does the quality control of observations. Variational bias correction is applied to satellite radiance observations.**


Flow chart of NCUM system (in Mihir HPCS)

**Hybrid variational-ensemble data assimilation combines the advantages of traditional variational method and ensemble data assimilation method to produce a superior quality analysis for the forecast model.**

**A hybrid 4D-Var/Ensemble Transform Kalman Filter (ETKF) algorithm was implemented for data assimilation in the NCMRWF Unified Model (NCUM) global NWP system in October, 2016 which was a significant milestone in the improvements of data assimilation capabilities at NCMRWF.**

**The hybrid 4D-Var data assimilation system of NCUM merges the background error covariance information from two sources:**

**(a) Climatological (Static)**

**(b) Flow-dependence errors from the NCMRWF Ensemble Prediction System (NEPS)**

# NCUM Hybrid 4D-Var

Background $\mathbf{x}^b$ and a transform $\mathbf{U}$ based on the error covariance $\mathbf{B}$ of $\mathbf{x}^b$

$$\mathbf{U}\mathbf{U}^T = \mathbf{B}$$

Control variable $\mathbf{v}$ which, via transform $\mathbf{U}$, defines likely corrections $\delta\mathbf{x}$ to $\mathbf{x}^b$

$$\delta\mathbf{x} = \mathbf{U}\mathbf{v}$$

Prediction $\mathbf{y}$ of observed values $\mathbf{y}^o$ using model $\underline{M}$ and observation operator $H$

$$\mathbf{y} = H\left(\underline{M}\left(\mathbf{x}_b + \beta_c \delta\mathbf{x}_c + \beta_e \delta\mathbf{x}_e\right)\right)$$

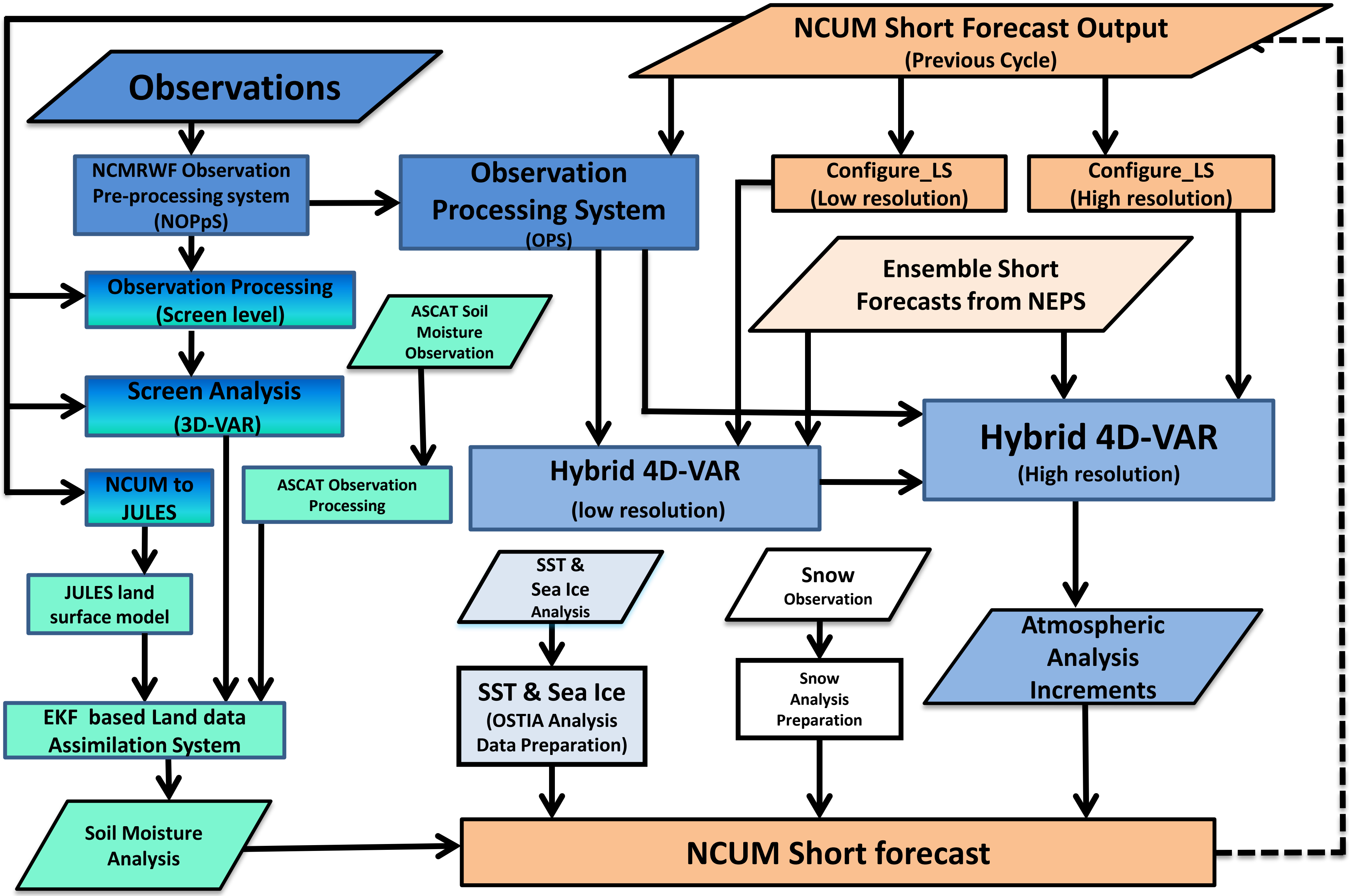
Measure misfit $J$ of incremented state to background and observations

$$J\left(\mathbf{v}\right) = \tfrac{1}{2}\mathbf{v}^T\mathbf{v} + \tfrac{1}{2}\left(\mathbf{y}-\mathbf{y}^o\right)^T \mathbf{R}^{-1}\left(\mathbf{y}-\mathbf{y}^o\right) \quad + Jc$$

Search for minimum of $J$, using gradient calculated using adjoint operators

$$\left(\frac{\partial J}{\partial \mathbf{v}}\right) = \mathbf{v} + \mathbf{U}^T\underline{\mathbf{M}}^T\mathbf{H}^T\mathbf{R}^{-1}\left(\mathbf{y}-\mathbf{y}^o\right)$$

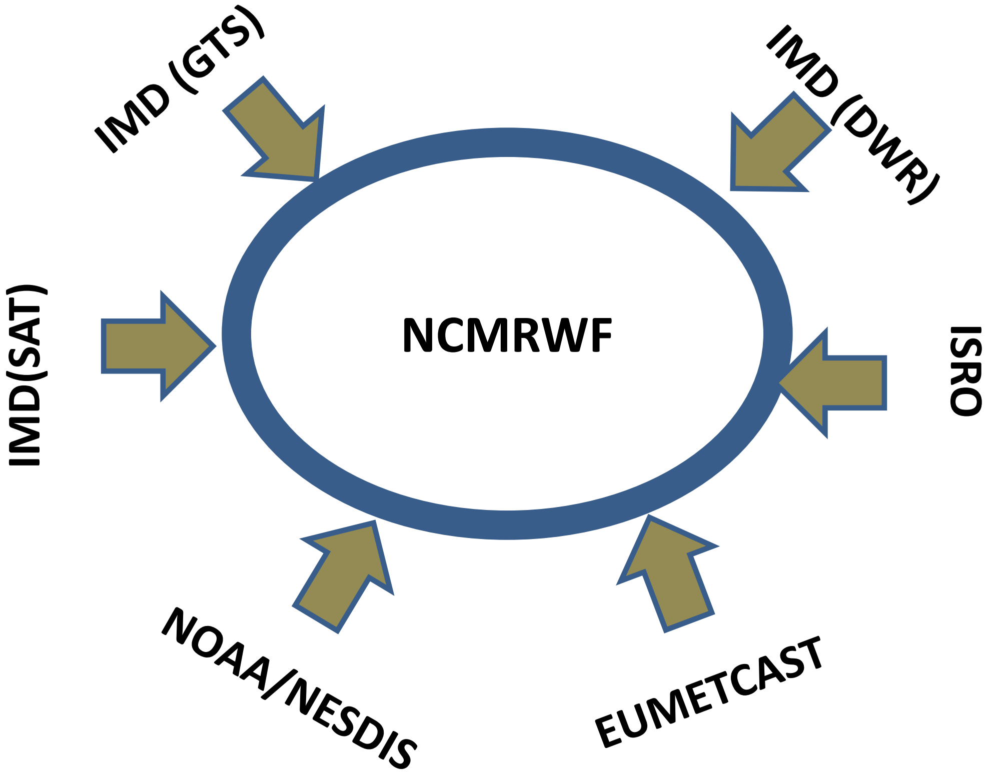
# NCUM Global Data Assimilation System



# NCMRWF Unified Model (NCUM) Global Data Assimilation System

| | Implementation Date | NCUM System (Version) | Data Assimilation (Atmosphere) | Land Data Assimilation | Atmos. Model Resolution |
|---|---|---|---|---|---|
| 4D-Var (Atmosphere) | April-2012 | NCUM-G:V1 | 4D-Var | UKMO Surface files | 25 km (UM : N512 L70) |
| Started Surface Analysis | Dec-2012 | NCUM-G:V2 | 4D-Var | Soil Moisture nudging | 25 km (UM : N512 L70) |
| Improved Land Data Assimilation-EKF | Nov-2015 | NCUM-G:V3 | 4D-Var | EKF (Soil Moisture) | 17 km (UM : N768 L70) |
| Hybrid 4D-Var (Atmosphere) | Oct-2016 | NCUM-G:V4 | Hybrid 4D-Var (Ensemble forecasts from ETKF system) | EKF (Soil Moisture) | 17 km (UM : N768 L70) |
| BE from high Resolution Ensemble. forecast | May-2018 | NCUM-G:V5 | Hybrid 4D-Var (Use of High resolution ensemble forecasts) | EKF (Soil Moisture, LST) | 12 km (UM : N1024L70) |
| Cloud Affected Radiance Assimilation (AMSU-A) | **June-2020** | **NCUM-G:V6** | **Hybrid 4D-Var (Use of High resolution ensemble forecasts)** | **EKF** (Soil Moisture, LST) | **12 km** (UM 11.2 : N1024L70) |

# Global Observation Reception at NCMRWF




## Global Observations Received at NCMRWF in Real Time

Low Earth Orbit Satellites

Aircraft

Surface Obs Over Land

Buoy

Geo Stationary Satellites

Radiosonde etc.
(Conventional upper air obs).

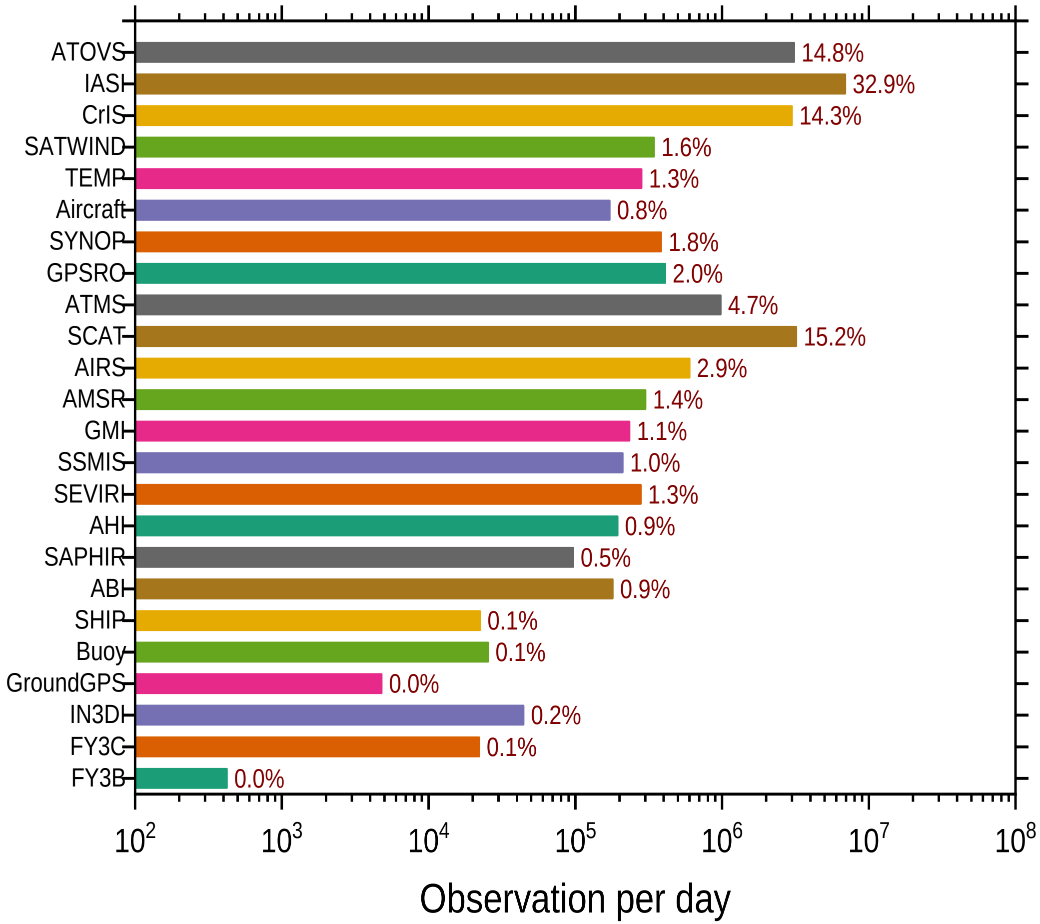
DWR

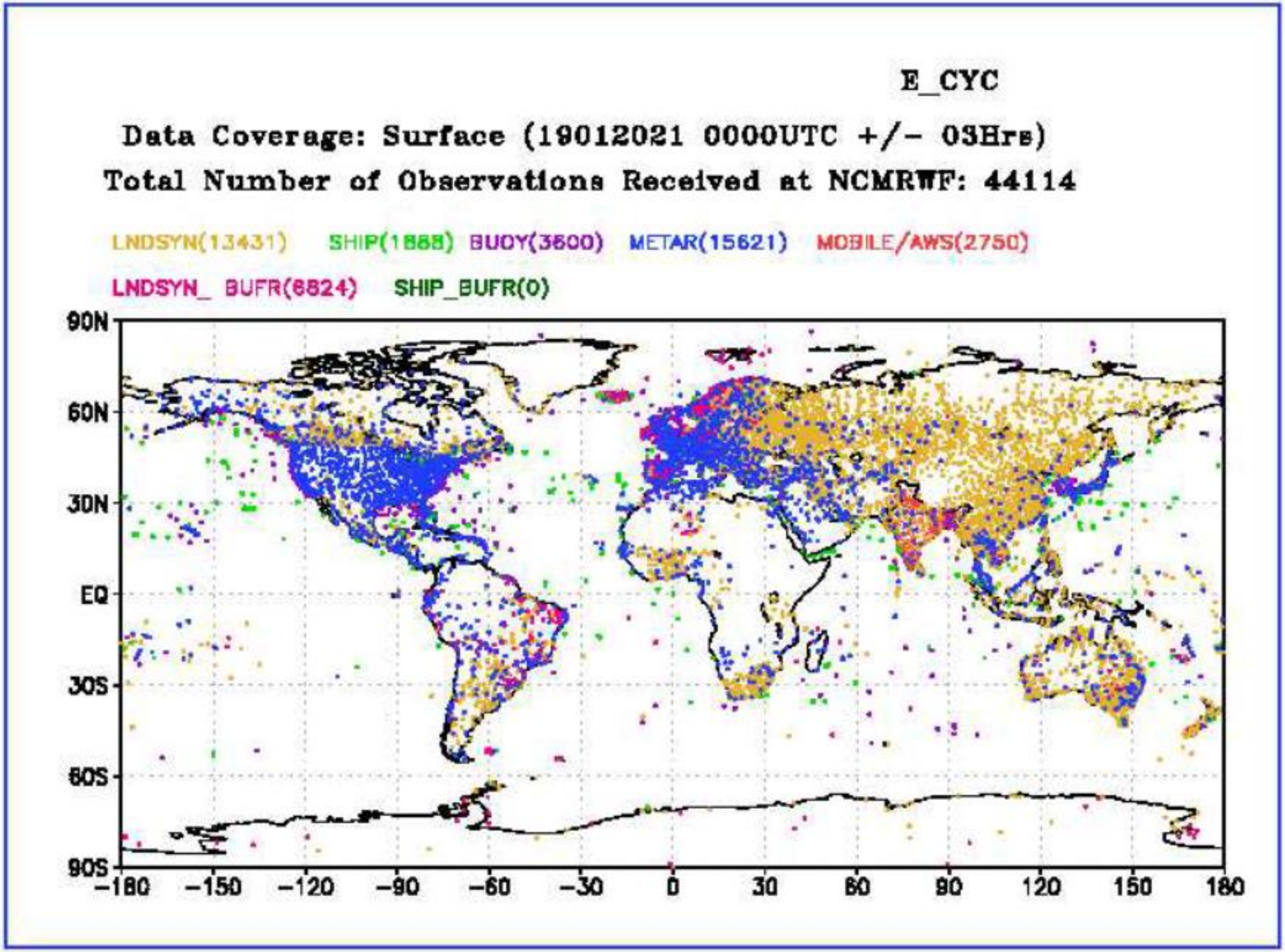
Ship

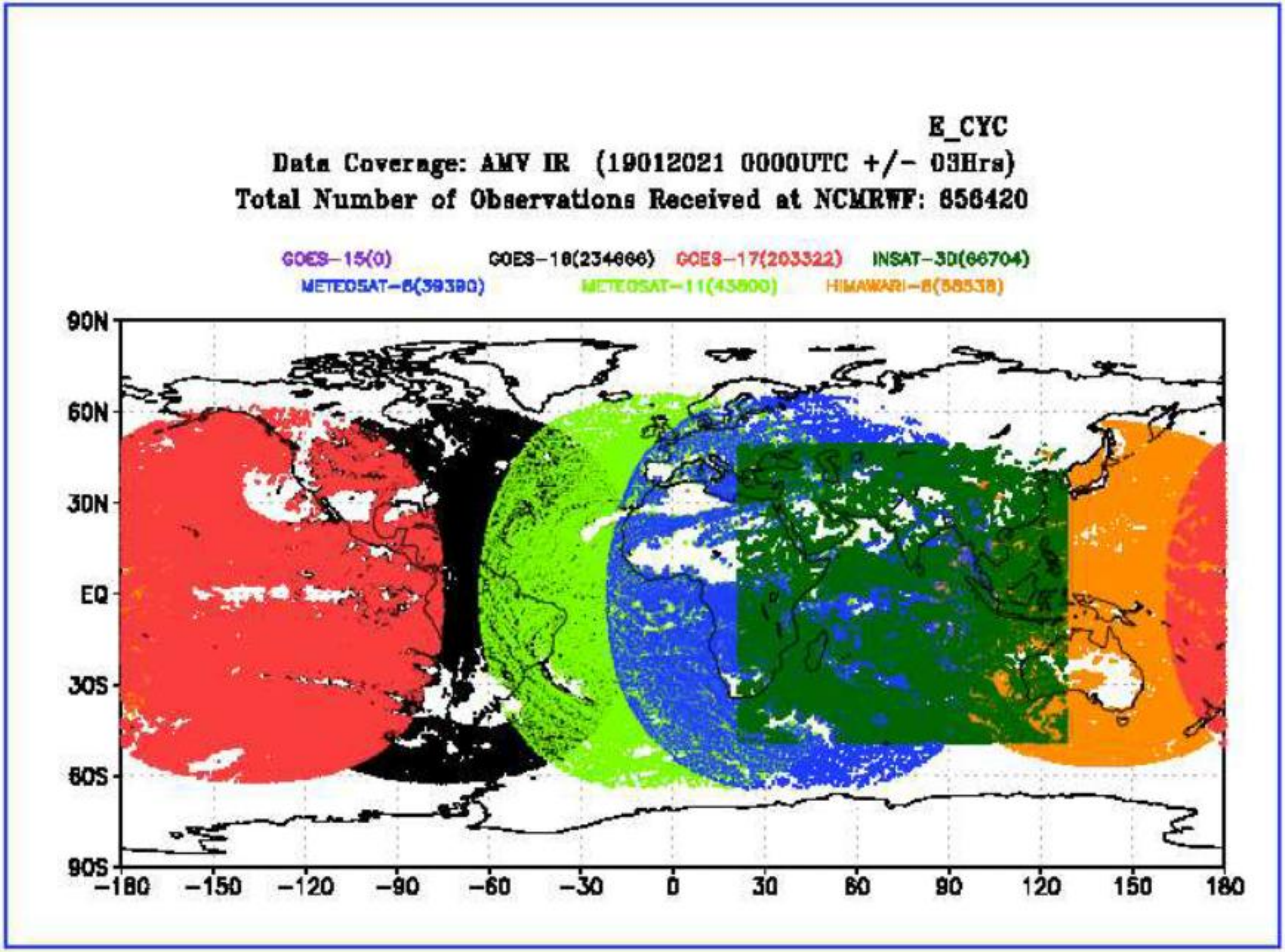
# Observations Assimilated in the NCUM Global Data Assimilation System

| Observation Type | Observation Description | Assimilated Variables |
|---|---|---|
| ABI | GOES Advanced Baseline Imager (ABI) radiances | *Brightness Temperature* ($T_b$) |
| AHI | Advanced Himawari Imager radiances from Himawari-8 | $T_b$ |
| Aircraft | Upper-air wind and temperature from aircraft | u, v, T |
| AIRS | Atmospheric Infrared Sounder of MODIS | $T_b$ |
| AMSR | Radiances from AMSR-2 onboard GCOM-W1 satellite | $T_b$ |
| ATOVS | AMSU-A (including cloud affected radiances), AMSU-B/MHS from NOAA-18 &19, MetOp-A&B | $T_b$ |
| ATMS | Advanced Technology Microwave Sounder in NPP& NOAA20 satellites | $T_b$ |
| CrIS | Cross-track Infrared Sensor observations in NPP & NOAA20 satellite | $T_b$ |
| FY3C | MWHS radiances from FY3C | $T_b$ |
| GMI | Global Precipitation Measurement (GPM) Microwave Imager (GMI) instrument | $T_b$ |
| GPSRO | Global Positioning System Radio Occultation observations from various satellites | Bending Angle |
| GroundGPS | Ground based GPS observations from various locations | Zenith Total Delay |
| IASI | Infrared Atmospheric Sounding Interferometer from MetOp-A&B | $T_b$ |
| IN3DImgr | INSAT-3D Imager Radiances | $T_b$ |
| SAPHIR | SAPHIR microwave radiances from Megha-Tropiques | $T_b$ |
| Satwind | Atmospheric Motion Vectors from various geostationary and polar orbiting satellites (including INSAT-3D& INSAT-3DR) | u, v |
| Scatwind | Advanced Scatterometer in MetOp-A & B, ScatSat-1, WindSat | u, v |
| SEVIRI | Cloud clear observations from SEVIRI of METEOSAT 8 & 11 | $T_b$ |
| Sonde | Radiosonde (TAC & BUFR),Pilot balloons, Wind profiles &Radar VAD winds | u, v, T, q |
| Surface | Surface observations over Land and Ocean (TAC & BUFR), TC bogus *(*Surface Pressure) | u, v, T, q, $P_s$ |
| SSMIS | SSMIS Radiances | $T_b$ |
| Radar (Indian DWR) | VAD Winds | u,v |

# Assimilated Observations




E_CYC
Data Coverage: Surface (19012021 0000UTC +/- 03Hrs)
Total Number of Observations Received at NCMRWF: 44114
LNDSYN(13431)
SHIP(1888)
BUOY(3600)
METAR(15621)
MOBILE/AWS(2750)
LNDSYN_ BUFR(6824)
SHIP_BUFR(0)
90N
60N
30N
EQ
30S
60S
90S
−180
−150
−120
−90
−60
−30
0
30
60
90
120
150
180


E_CYC
Data Coverage: AMV IR (19012021 0000UTC +/- 03Hrs)
Total Number of Observations Received at NCMRWF: 656420
GOES-15(0)
GOES-16(234666)
GOES-17(203322)
INSAT-3D(66704)
METEOSAT-8(39390)
METEOSAT-11(43800)
HIMAWARI-8(68538)
90N
60N
30N
EQ
30S
60S
90S
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180

# Immediate Future Plan

ETKF scheme will be replaced with an advanced ensemble of 4D-ensemble-Var (En-4DEnVar) scheme (Bowler *et al.*, 2017) shortly

***Thank You***